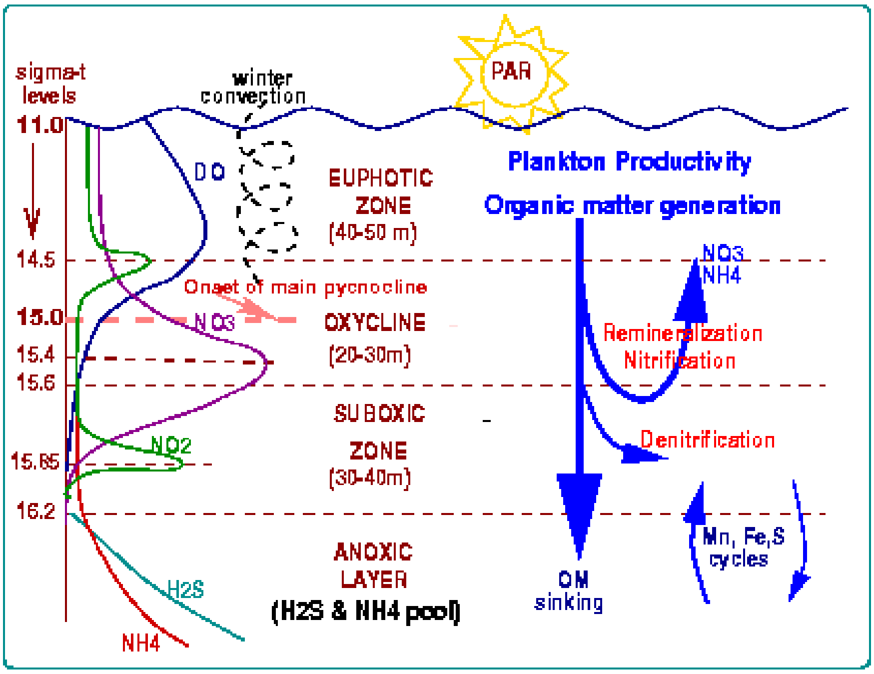
OBSERVATIONS AND MODELING OF THE BLACK SEA ECOSYSTEM

The vertical biogeochemical structure of the Black Sea comprises four distinct layers.



(For more details see http://www.ims.metu.edu.tr/cv/oguz/bio-pump.htm)

Since the end of last century modeling of the Black Sea ecology has been intense developed. In mid ninetieths there was constructed a one-dimensional nitrogen-based, vertically resolved, coupled physical-biological model of the lower trophic level to examine the first order physical and biological processes controlling the seasonal cycle of the plankton productivity in the surface waters of the Black Sea (Oguz et al., 1996). The biological part of the model was kept quite simple, including only single phytoplankton and herbivore zooplankton groups (1P1Z), detritus, nitrate and ammonium, which form the “minimum critical set” (GLOBEC, 1995). The model was applied for conditions appropriate to the central Black Sea, which possesses simpler ecosystem behavior than do the highly complex western shelf and Rim Current frontal zones. This model had a reasonable success in reproducing monthly variations of the upper layer water column stratification characteristics. It demonstrated the crucial role of mixed layer dynamics during convective overturning events, which are missing in most ecosystem models. The biological component of this coupled model was able to simulate the spring and fall blooms and the summer subsurface chlorophyll maximum layer. This simple model was useful for examining the basic physical and biological processes controlling the seasonal cycle of plankton productivity in the Black Sea. One drawback of the simplified 1P1Z ecosystem model was underestimation of the summer production. The summer subsurface chlorophyll concentrations were found to be somewhat lower than observed values. The limited capability of 1P1Z models in predicting summer chlorophyll values was noted earlier by Sarmiento et al. (1993) in their North Atlantic model. Armstrong (1994) pointed out that multiple prey-multiple predator models can alleviate the limitations imposed by 1P1Z approaches and, as in the North Atlantic case, may generate increased chlorophyll concentrations comparable with observations.

In work (Oguz et al., 1999, http://www.ims.metu.edu.tr/cv/oguz/PDFs/oguz_etal_DSR99.pdf) two phytoplankton species groups, typifying diatoms and flagellates, and two zooplankton groups (micro- and mesozooplankton) were introdused. Then, it was shown how this slightly more complex representation of plankton food web structure leads to enhanced production during late spring and summer in the Black Sea model. In view of growing recognition of its importance, there was also included a simple representation of ammonium oxidation (nitrification).

According to observations the Black Sea has a major diatom bloom during March (Sorokin, 1983; Vinogradov, 1992; Vedernikov and Demidov, 1993). A second bloom occurs sometime during autumn. Two or more additional phytoplankton peaks, mainly of coccolithophorids and flagellates, are usually observed during late spring and summer (Bologa, 1986). Emiliania huxleyi blooms occurring in the months of June and July are evident in the CZCS imagery (Sur et al., 1996). The early spring bloom is the most robust feature of the yearly phytoplankton structure and is present in every data set (see Koblentz-Mishke, 1970; Sorokin, 1983; Lebedeva and Vostokov, 1984; Vedernikov and Demidov, 1993). Formation and timing of summer blooms, on the other hand, seem to be much more sensitive to local conditions and exhibit considerable regional and interannual variability (Vinogradov, 1992; Vedernikov and Demidov, 1993; Sur et al., 1996).

The structure and functioning of plankton communities of open sea areas of the Black Sea before and after the invasion were studied using a two-layer dynamics model (0-25 m and 25-75 m) in Lebedeva and Shushkina (1993). The following components of the ecosystem were identified in their model: total phytoplankton, bacteria, protozoans, mesoplankton; (jellyfish and ***Pleurobrachia*** combined into one element) and ***Mnemiopsis***. Dissolved organic matter, detritus and non-organic phosphorus were also included into a set of state variables. Fish populations were not considered.

The main purpose of the model of Volovik et al. (1995) was to forecast comb jelly biomass dynamics in the Azov Sea. One of the most important modules in this ecological-mathematical model estimates water exchange between the Black and Azov Seas and the Azov Sea salinity.

Thirteen species of zooplankton and ***Mnemiopsis*** were included in a state variables vector, temperature, salinity, food concentration for zooplankton were considered as a controlling (driving) factors and spatially the Azov Sea surface water was subdivided into eight segments.

However, modelling results were only presented for seasonal dynamics of zooplankton and ***Mnemiopsis*** total biomass in 1993.

The Christensen and Caddy (1994) study of the impact of introducing ***Mnemiopsis***, the option of introducing a potential predator, ***B. beroe*** was evaluated using a simple stationary model of energy flows in the Black Sea pelagic ecosystem ECOPATH II (Christensen and Pauly,1992). This model included other variables such as fish, fish larvae, Aurelia, phytoplankton and detritus, in predicting the effect of ecosystem change following these introductions.

A one-dimensional coupled physical-biogeochemical model, together with reanalysis of the available data, were used to provide a new perspective for identification and interpretation of the suboxic layer (SOL) of the Black Sea. While the lower boundary appears to be stable at $\sigma_t \approx 16.15 \pm 0.10$ kg m^{-3}, the upper boundary is found not to be isopycnally uniform as asserted previously. It is found to vary depending on the intensity of vertical diffusive and advective oxygen fluxes across the oxycline. Its position, therefore, does not always correspond to a distinct density surface irrespective of the circulation characteristics. Instead, it changes from $\sigma_t \approx 15.55 \pm 0.1$ in cyclonic to $\sigma_t \approx 15.9 \pm 0.1$ kg m^{-3} in anticyclonic regions, whereas its position in the peripheral Rim Current transition zone occurs at intermediate density values. These findings imply that vertical oxygen variations cannot be expressed in terms of density without taking into account physical characteristics of the water column. The presence of very strong density stratification is found to prevent ventilation of the SOL. Even intense turbulent mixing generated by a large buoyancy loss during an exceptionally cold winter season is unable to generate sufficiently dense water to overturn and temporarily supply oxygen into the suboxic zone. http://www.ims.metu.edu.tr/cv/oguz/PDFs/2001GB001465.pdf

Other examples of interdisciplinary studies integrating the Black Sea biogeochemistry and circulation dynamics were done in http://www.ims.metu.edu.tr/cv/oguz/PDFs/oceanography.pdf.

An examination of a wide spectrum of hydro-meteorological and biogeochemical records in the Black Sea from the previous 11 century possesses a robust climatic signature at interannual to interdecadal time scales. Superimposed on the first eigenmode of the 12 data with interdecadal changes on the order of 15 to 30-year band, the second mode reflects oscillations with the period of about 10 13 years. The cold and dry winters generally take place within the first half of each decade, and they switch to mild and warm winters 14 during the second halves. All the water column physical and biogeochemical properties examined respond accordingly to such 15 oscillations. For example, the years with the cold (mild) winters correspond to the periods of increasing (decreasing) nutrient and 16 hydrogen sulfide concentrations, phytoplankton biomass.

These variations appear to be governed by the North Atlantic Oscillation 17 (NAO) and East Atlantic-West Russia (EAWR) teleconnection patterns comprising various combinations of the low and high 18 surface pressure anomaly centers over the North Atlantic and Eurasia. The NAO teleconnection to the Black Sea is opposite to that 19 taking place in the eastern North Atlantic and its marginal seas. The relatively cold and dry winters occur during the positive phase 20 of the NAO, and visa versa for the milder and wetter winters. The Black Sea Climate Index, constructed using more than 100-year-21 long time series of the North Atlantic Oscillation, the sea surface temperature, air temperature, sea level anomaly, provides a 22 composite representation of the dominant mode of regional climate variability, and explains 46% of the total variance. The results 23 point to a very efficient coupling between the anthropogenic and climatic forcing for driving the dramatic ecosystem changes 24 observed during the 1980s and 1990s. http://www.ims.metu.edu.tr/cv/oguz/PDFs/JMS_Climate_proof.pdf

The Black Sea ecosystem is shown to experience abrupt shifts in its all trophic levels from primary producers to apex predators in 1995–1996. It arises as a manifestation of concurrent changes in its physical climate introduced by intensive warming of its surface waters as well as abrupt increases in the mean sea level and the net annual mean fresh water flux. The warming is evident in the annual-mean sea surface temperature (SST) data by a continuous rise at a rate of $\approx 0.25^0$C per year, following a strong cooling phase in 1991–1993. The most intense warming event with $\approx 2^0$C increase in the SST took place during winters of the 1994–1996 period. It also

coincides with 4 cm yr^{-1} net sea level rise in the basin, and substantial change in the annual mean net fresh water flux from 150 km^3 yr^{-1} in 1993 to 420 km^3 yr^{-1} in 1997. The subsurface signature of warming is marked by a gradual depletion of the Cold Intermediate Layer (characterized by $T < 8^0$C) throughout the basin during the same period. Winters of the warming phase are characterized by weaker vertical turbulent mixing and upwelling velocity, stronger stratification and, subsequently, reduced upward nutrient supply from the nutricline. From 1996 onward, the major late winter-early spring peak of the classical annual phytoplankton biomass structure observed prior to mid-90s was, therefore, either weakened or disappeared altogether depending on local meteorological and oceanographic conditions during each of these years. The effect of bottom-up limited unfavorable phytoplankton growth is reflected at higher trophic levels (e.g., mesozooplankton, gelatinous macrozooplankton, and pelagic fishes) in the form of their reduced stocks after 1995. http://www.ims.metu.edu.tr/cv/oguz/PDFs/oguzetal2003.pdf

In the work (http://www.ims.metu.edu.tr/cv/oguz/PDFs/DSR.pdf) the reactions controlling the suboxic-anoxic interface structure in the Black Sea are investigated with a prognostic, one-dimensional vertically resolved diffusion-reaction model involving O_2, NO_3-, NH_4^+, HS-, S^0, Mn^{2+},

MnO_2. All reactions are expressed in a second-order form, and values for the rate constants are estimated from laboratory and field measurements made during the 1988 RV Knorr expedition. The model successfully simulates the vertical profiles of O2, N, S and Mn species in the region between upper and lower boundaries of the model, which were specified at depths corresponding to $\sigma_t \approx 15.50$ kg/m3 and $\sigma_t \approx 16.50$ kg/m3. The model identifies an approximately 30 m thick suboxic layer with oxygen concentrations less than 5 lM and zero sulfide concentrations between $\sigma_t \approx 15.55$ kg/m3 and $\sigma_t \approx 16.05$ kg/m3. Dissolved oxygen decreases to trace concentrations above the zone of nitrate reduction. Hydrogen sulfide begins to increase downward into deeper levels of the anoxic pool starting at $\sigma_t \approx 16.0$ kg/m3, where nitrate becomes undetectable. Dissolved manganese and ammonium also increase beneath the suboxic layer. The position at which sulphide concentrations appear coincides with the particulate manganese peak, reflecting the paramount role of manganese cycling in the redox processes. This structure is found to have a fairly persistent character for a wide range of rate constants. Oxidation reactions by oxygen alone are not sufficient to provide a realistic interface structure in the absence of particulate manganese formed by oxidation of Mn^{2+} by NO_3-. A transient lateral oxygen supply into sulphide rich waters alters the anoxic-suboxic structure by rapidly depleting local sulfide concentrations at the depths of oxygen injection.

The basic physical and biological dynamics of upper ocean coupling physical and biogeochemical models are illustrated. The physical models used are one-dimensional mixed layered model and a 3-dimensional, primitive equation hydrodynamic model. The biogeochemical model is based on the European Regional Ecosystem Model (ERSEM). The model consists of five modules: (1) primary producers, (2) microbial loop, (3) mesozooplankton, (4) benthic nutrients, and (5) benthic biology. The ecosystem in ERSEM is subdivided into three functional types, producers (phytoplankton), decomposers (pelagic and benthic bacteria) and consumers (zooplankton and zoobenthos). The model is forced by monthly records of Danube nutrients concentrations at the river outflow. The effect of nutrient discharge on the quality of a given ecosystem is tested by looking at the ecosystem behaviour in several periods, characterised by different nutrient discharge rates.

http://danubs.tuwien.ac.at/Poster/Staneva_et_al_EGS2002.pdf

The ecological model BIOGEN, describing the carbon, nitrogen, phosphorus and silicon cycling throughout aggregated chemical and biological compartments of the planktonic and benthic marine systems, has been implemented in the north-western Black Sea to assess the response of this coastal ecosystem to eutrophication by the Danube River.

http://www.icbm.de/~physoz/download/stanev02c.pdf

A 6-compartment biogeochemical model of nitrogen cycling and plankton productivity has been coupled with a 3D general circulation model in an enclosed environment (the Black Sea) so as to quantify and compare, on a seasonal and annual scale, the typical internal biogeochemical functioning of the shelf and of the deep sea as well as to estimate the nitrogen and water exchanges at the shelf break. Model results indicate that the annual nitrogen net export to the deep sea roughly corresponds to the annual load of nitrogen discharged by the rivers on the shelf.

The model estimated vertically integrated gross annual primary production is 130 g Cm^{-2} yr^{-1} for the whole basin, 220 g Cm^{-2} yr^{-1} for the shelf and 40 g Cm^{-2} yr^{-1} for the central basin. In agreement with sediment trap observations, model results indicate a rapid and efficient recycling of particulate organic matter in the sub-oxic portion of the water column (60–80 m) of the open sea. More than 95% of the PON produced in the euphotic layer is recycled in the upper 100m of the water column, 87% in the upper 80 m and 67% in the euphotic layer. The model estimates the annual export of POC towards the anoxic layer to 4 1010 mol yr^{-1} This POC is definitely lost for the system and represents 2% of the annual primary production of the open sea.

http://www.biogeosciences.net/1/33/2004/bg-1-33-2004.pdf

A six-compartment ecosystem model defined by a simple nitrogen cycle is coupled with a general circulation model in the Black Sea so as to examine the seasonal variability of the ecohydrodynamics. Model results show that the annual cycle of the biological productivity of the whole basin is characterized by the presence of a winter–early spring bloom. In all the regions this bloom precedes the onset of the seasonal thermocline and occurs as soon as the vertical winter mixing decreases. Phytoplankton development starts in winter in the central basin, while in coastal areas (except in the river discharge area) it begins in early spring. In the Danube's discharge area and along the western coast, where surface waters are almost continuously enriched in nutrient by river inputs, the phytoplankton development is sustained during the whole year at the surface. The seasonal variability of the northwestern shelf circulation induced by the seasonal variations in the Danube discharge and the wind stress intensity has been found to have a major impact on the primary production repartition of the area. In the central basin the primary production in the surface layer relies essentially on nutrients being entrained in the upper layer from below. Simulated phytoplankton concentrations are compared with satellite and field data. It has been found that the model is able to reproduce the main characteristics of the space-time evolution of the Black Sea's biological productivity but underestimates the phytoplankton biomass especially in regions extremely rich in nutrients such as the Danube discharge area. http://www.agu.org/pubs/crossref/2004/2001JC001014.shtml

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